AN INTERRANGE COMPARISON IN SUPPORT OF THE CHARACTERISATION OF SPACE ANTENNA SYSTEMS AND PAYLOAD TESTING.

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Abstract:

The recent construction at Matra Marconi Space Portsmouth of a new 1-50GHz, 22m by 8m scan area planar near field antenna measurement system, taken together with the existence of the large Spherical near field range on the same site, has presented opportunities to compare results obtained in two very different antenna measurement facilities.

This paper gives a comparative description of the facilities, and an overview of the measurement process in each range as applied to the measurement of spaceborne antennas. Results of a study undertaken to establish the similarity between results obtained by each range when measuring the same instrument are then summarised.

The results show encouraging similarity given that the measurement geometry, RF subsystems, control computers, positioner hardware, near field-far field transform software, software correction techniques, alignment correction methods and alignment measurement procedures are different in each facility. It should also be remembered that the planar and spherical techniques are optimised for different classes of antenna.

Introduction:

Antenna measurement in the space industry presents specific challenges perhaps not encountered in other areas of application. Not least of these is the requirement to characterise the radiation pattern in an angular or other co-ordinate set relative to a fixed mechanical interface with high precision. With edge-of-cover (EOC) gain slopes as high as 10 or 20 dB per degree, and spacecraft mission lifetimes dictated by fuel usage which in turn depends on the tolerances set on spacecraft attitude control, fractions of a degree error in antenna pointing between design and in-service performance can have significant implications on mission effectiveness. Similarly, the polarisation purity of linear antennas (required for polarisation reuse schemes) dictates that antenna alignment in test and installation is known to fractions of a degree. It goes without saying that the antenna alignment cannot be adjusted in orbit. Other challenges include testing at temperatures other than ambient, and the stringent control of test conditions required to allow comparison of results obtained before and after environmental simulation (‘shake and bake’) and to comply with the traceability requirements covering all space hardware.

Generic measurement process:

The aim of the range measurement process is to characterise the radiation pattern of the antenna under test (AUT) with reference to an angular or other co-ordinate set which is defined from a fixed mechanical interface. Typically, absolute gain measurements are required, and angular accuracies required are demanding, particularly where the antenna is to be mounted on a spacecraft destined for geostationary orbit (from which altitude the Earth subtends an angle of only ±8.7 degrees)

The measurement of absolute gain is a topic in itself, and it is not the purpose of this paper to cover it. Typically, the substitution method using a calibrated standard is implemented.

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Figure 1, illustrates the process as an overview. The measurement of the pattern relative to the antenna mechanical interface necessitates accurate determination of the alignment of the interface relative to the range co-ordinate system during the acquisition of the near field results. This determination is one of the early steps in the process. The known alignment can then be corrected for later. The method of correction is described in some detail below. Once the alignment has been captured, the near field scanning process is performed. Following this, the measured near field data is processed to yield corrected far field results. These results are typically presented in Ludwigs 3rd co and crosspolar basis referenced to a specified *electrical boresight system* (that system which defines the copolar direction) which may or may not be coincident with the *antenna plotting system* (the output system in which the field quantities are tabulated).

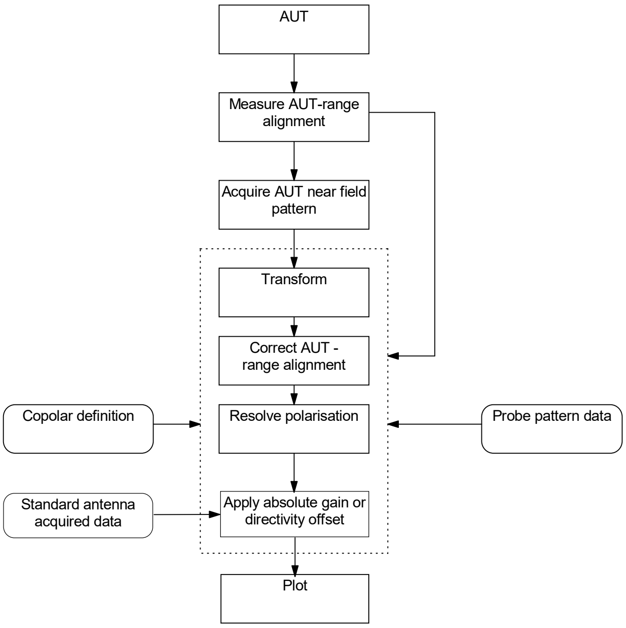

Figure 1

Mathematical basis:

In principle both the spherical and planar techniques are endeavouring to derive a complex vector field function at a large (or infinite) distance from the antenna, from the sampling of similar complex data over a well understood surface at a much smaller distance (which allows testing of electrically large antennas in a controlled, indoor, environment). In both cases the acquisition of the near vector field is accomplished by placing a probe at a particular position pointing in a particular direction and allowing the electric field which surrounds the probe to generate an observable excitation current. The difference in potential between the probe and a reference is sampled in phase and at quadrature. Provided that two such orthogonal complex voltages are sampled over a well defined surface at regular intervals, the principal of modal expansion can be utilised to determine the amplitudes and phases of an angular spectrum of plane, cylindrical or spherical waves (there is a mathematical convenience in choosing a modal basis geometry which matches the measurement geometry). This then facilitates the computation of the fields at any distance from the AUT and hence the computation of the fields at infinity which results in a true far field vector pattern.

Despite the obvious similarities between the theoretical descriptions at the generic level, the differing geometries result in a significant divergence in the specific implementation of each. In order for the Spherical near-field to far-field range (SNFFFR) to characterises the propagating near-field component a test probe is held at rest whilst the antenna under test (AUT) is nodded in phi and rotated in theta, where theta and phi are conventional spherical co-ordinates. This results in the path of travel of the probe describing a spherical surface which is attached to the AUT. This experimental set-up is in stark contrast to the Planar near-field scanner (PNFS) where it is the AUT which remains at rest whilst a small light probe is scanned across the aperture of the AUT. Both techniques are subject to the same sorts of experimental uncertainties; however they are manifested in distinctly different ways.

Description of facilities:
Table 1 below shows a comparison of the major features of each test facility.

Feature	**Planar Scanning Range**	**Spherical Range**
Mechanical subsystem		
Positioners	Orbit FR	Scientific Atlanta
Alignment aids	Precision contacting probe	Theodolite - optical cube
Alignment measurement process	In-situ measurement of antenna mechanical interface	Two-step process involving optical cube as arbitrary fiducial reference
Control subsystem		
Acquisition software source	Orbit FR	Scientific Atlanta
Positioner readout	Inductosyn and laser interferometer	Optical encoder
RF Subsystem		
Source's	Hewlett Packard	Scientific Atlanta
Receiver	Hewlett Packard	Scientific Atlanta
Probes	Low RCS	
Transform		
Sampled field component	Cartesian	Spherical
Minimum Sampling criteria	Increment interval half wavelength on surface of acquisition plane	Increment angle subtends half wavelength on surface of minimum sphere
Sampling grid	Rectangular Cartesian	Polar / equatorial spherical
Software source	MMS	TICRA / MMS modifications
Alignment correction	Output grid distortion	Spherical mode manipulation
Probe correction	Pattern correction always used. Tabulated pattern from measurements or automensurated probe pattern	Only required for short range lengths. Spherical mode model used.
Modal basis	Plane wave spectrum	Spherical modes
Data output		
Output file	ASCII tabulation of selected field components on regular azimuth-over-elevation grid	
Display routine	In-house plotting software	

Table 1

With respect to the range process, as outlined above, the primary difference between the two facilities is the method of capturing the antenna to range alignment and the method of applying these corrections.

Alignment measurement: Planar range The acquisition of alignment data in the planar facility is based upon the premise of being able to measure four points on the antenna mechanical interface plane in the range co-ordinate system. If the mechanical datum is not directly accessible then small z corrections supplied from the AUT geometric design are applied by assuming that the antenna z axis is approximately parallel with the range z axis. From these four points we can construct four normals, the average angles between each can be used to calculate the RMS. This RMS value can be taken as an indication of the measurement error. The correct projection of each Cartesian components of the first system onto each Cartesian component of the second system determines the antenna to range mechanical alignment direction cosine matrix. For the case where their is a suitable datum available on the antenna the roll angle can be deduced from any of the edge vectors.

Alignment measurement: Spherical range The acquisition of alignment data within the spherical facility is based upon the premise of being able to acquire at least two surfaces of an optical cube when the instrument is mounted a) outside the range with the mechanical interface aligned accurately to gravity and a master theodolite, and b) inside the range on the range positioner system. In the former case, the theodolite readouts enable the cube-to-mechanical-interface alignment to be determined. In the latter, the relationship between the theodolite angles and the range positioner readouts enables the alignment of the cube faces to the range co-ordinate system to be determined. Two direction cosine matrices are deduced from this process. The multiplication of the these matrices results in the formulation of the antenna interface to range mechanical system direction cosine matrix.

Alignment correction: spherical range The antenna to spherical range alignment correction is applied rigorously without the aid of interpolation by performing a series of rotations, defined in terms of Euler angles, to the spherical mode coefficients. These rotated coefficients can then be expanded into field components which can be resolved onto the required polarisation basis.

Alignment correction: planar range For the case of the planar range the application of alignment correction data is applied rigorously by expanding the plane wave spectrum on an irregular grid in the range system. This irregular space corresponds to a regular angular domain in the antenna mechanical system. Again, the field components then need transforming from the range polarisation basis into the antenna polarisation basis.

Probe effects: In both cases, the probe pattern affects the fields received from different parts of the AUT. In the spherical range, this is often negligible because of the long range length and low gain of the probe. In the planar range, the effect includes something similar to a direct multiplication of the probe pattern with the antenna pattern in the far field. This results from the convolution of the near field pattern of the probe with that of the AUT, which may be visualised directly from the mechanical operation of the scanner. It is not usually possible to neglect these effects in the planar range because of the angles of validity required and the short measurement distance. Care has to be taken over which co-ordinate system, and which field components, the probe convolution is understood to have taken place so that a rigorously correct deconvolution can be applied.

Example Results and Discussion:

A complete end to end 'black box' comparison was not possible due to the unavailability of optical alignment data from the planar facility, in the absence of which an alternate scheme was sought. This was to check alignment in the planar range in isolation, and pattern agreement only between the ranges.

A low gain mechanically rigid instrument was selected so that effects due to gravitational deformation could be neglected. A probe antenna, whose pattern was not perfectly circularly symmetric, was used to scan the AUT so that any error in the understanding of the orientation or pattern of the probe would become apparent.

The results are presented in the form of overlaid contour plots. These were chosen over pattern cuts because they present the full pattern and allow gross effects to be seen in addition to local differences.

Planar range alignment correction: In order that the validity of the alignment techniques employed in the planar range could be tested, an antenna was acquired in the range at a variety of different orientations. The antenna to range alignment was measured as described above in each case and the data transformed. A successful overlay of the results demonstrates that the alignment correction and measurement techniques do not contain mathematical errors such as sign errors or substitution of θ for sinθ. Large angles (20 or 30 degrees) were used to highlight such errors. This test also demonstrates that, truncation effects aside, the same far field pattern can be obtained independent of the illumination of the scan plane. It also gives some confidence in the probe deconvolution implementation as different parts of the probe pattern are used and different vector relationships of field components occur in each case.

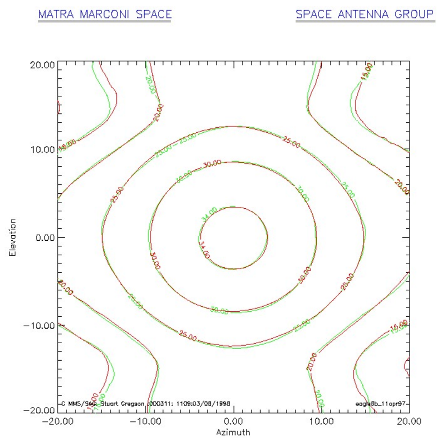

Figure 2.
AUT Alignment Test.

Planar range probe correction checks: The AUT was acquired several times with the probe at a variety of differing orientations. The design of the probe carriage allows for the rotation of the probe through an arbitrary but accurate angle. The implementation of probe deconvolution involves several scalar interpolations and vector resolutions. In order to achieve confidence that the vector spaces were understood correctly, it was decided to measure an AUT with the probe at a variety of roll angles and overlay the results. This checks for consistency in the probe deconvolution and probe data handling code.

Inter range comparison: Another mechanically rigid instrument was employed for the interrange comparison. This instrument was characterised in the spherical and planar facilities and the measurements compared. Due to the lack of comparable alignment data the alignment of the patterns were optimised by the application of a series of scalar rotations, determined by inspection. Comparison of these results adds to overall confidence in both test facilities. The agreement achieved is within the published error budget for the planar range, i.e. ± 2dB at -40dB. This makes no allowance for errors in the spherical range measurement.

Conclusion:

The availability on the same site of two very different antenna test facilities has allowed some comparison work to be performed. Unfortunately, the extent of this work has been limited by the fact that both are ‘on-line’ industrial facilities in constant use. However, the results which have been obtained are encouraging.

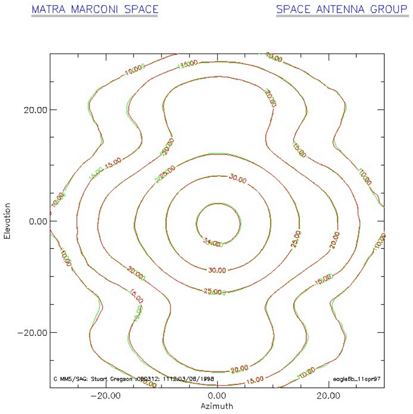

Figure 3
Probe Alignment Test.

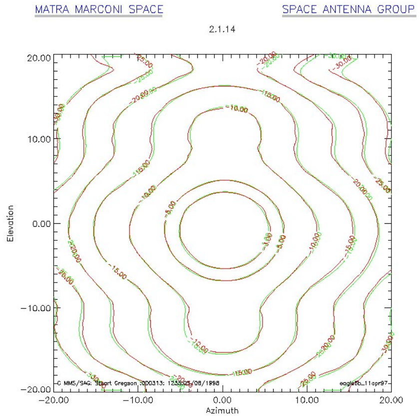

Figure 4
SNFFFR-PNFS Inter Range Test.

Additional Reading:

1. R. H. Clarke & J. Brown: “Diffraction Theory and Antennas”.
2. J. E. Hansen: “Spherical Near-Field Antenna Measurements”.